for each vehicle. In the facility, one component is attached to the motion system, while the other component is mounted to the force/moment sensor fixed in the support structure above the 6 DOF. The six components of the contact forces/moments acting on the test article and its mating component are measured by the force/moment sensor. The force/moment sensor is interfaced to the real-time Alliant computer system.



## Space Shuttle Program - Automatic Rendezvous, Proximity Operations, and Capture

by William Jackson et al, NASA JSC

An overview of the current NASA Johnson Space Center capabilities and ongoing activities for the design, development and demonstration of AR&C capabilities was provided. The JSC plans for ground and flight tests/demonstrations of progressive AR&C capabilities, using the Space Shuttle are described. The Space Shuttle could provide an effective "flying test bed" for these demonstrations.

A number of organizations at NASA JSC which responsibilities and capabilities associated with AR&C: the Flight Crew Operations Directorate includes the Astronaut Office, Space Shuttle Support, Office and Space Station Support Office, the Mission Operations Directorate includes the Systems Division provides mission support for Space Shuttle systems, training, operations, flight design and dynamics and Space Shuttle ground systems and the Engineering Directorate which provides engineering support to the Space Shuttle Program. The JSC can provide the following facilities: 6 DOF test facility, GPS test bed, Electro-optics Laboratory, Inertial Systems Laboratory, GN&C Emulator test bed, 6-DOF Docking Dynamic Test System, Robotics and Mechanical Systems Laboratory, Integrated Graphic Operation Analysis Laboratory and Intelligent Systems Laboratory.

The JSC proposes a phased approach to flight demonstrations of AR&C capabilities to minimize impact on the Orbiter and Orbiter operations. The priorities in this phasing are: (1) proximity operations, (2) capture, and (3) rendezvous. Priority is based on a combination of expected return on investment and complexity in integration with the Orbiter.

A four-stage flight demonstration is proposed. The four stages allow for a progressive development, application, integration, and demonstration of AR&C capabilities, that is consistent with the development schedules of the supporting systems and opportunities for Orbiter flight tests. The actual number of sequence of flight demonstrations is still under study and several options are being considered to optimize the costs and complexity of the demonstrations with the benefits. These stages fall into one of three ranges of operations: rendezvous - liftoff to 2 km, proximity operations from 2 km to 15 km; or capture/release - <15 km.

The Stage 1 Flight Demonstration is an open-loop flight test of a laser sensor which provides range, range rate, and bearing information to the Orbiter flight crew via supplemental displays, while the Orbiter is operating in the proximity operations zone of the target (e.g., 2 km to 50 ft). In this region, there is essentially no potential for Orbiter and target vehicle collision, regardless of the performance of the augmented system. Advanced targeting and guidance algorithms would be exercised in a "background," using information from the laser sensor to compute commands as though the loop were closed.

Based on the experience and confidence provided by the Stage 1 Demonstration, the Stage 2 Demonstration would extend the use of the supplemental Orbiter flight crew displays and GN&C algorithms to support manual operations from proximity operations to a capture position. Stage 2 also is an open-loop flight demonstration that moves the Orbiter within the capture range of the target vehicle. It can include flight tests of sensors for active docking mechanisms and/or automatic tracking by a manipulator in this flight envelope.

Stage 3 will be conducted as a two part demonstration. Stage 3a is relatively independent of the other stages since the techniques and systems required for proximity operations and capture do not depend heavily on the rendezvous operations. The automatic rendezvous capabilities to be demonstrated include: extended range tracking via GPS, automatic operations management, and onboard trajectory control, and systems management across the required rendezvous maneuvers. Automatic rendezvous could be initiated from a "standard" parking orbit or it could be comprehensive and include a "ground-up" automatic rendezvous operation.

Stage 3b will use an automatic system to maintain relative position, velocity, and altitude between the Orbiter and target vehicle along a desired relative approach profile (from approximately 2 km to 15 m). The key system elements include a laser radar for relative state measurements; closed-loop translational state targeting algorithms and automated delta-velocity guidance; optimal jet selection for efficient translational and rotational control; collision monitoring and prediction; automatic fault detection, isolation, and recovery for the avionics components; and an orbit maneuver replanner/scheduler/sequencer which accommodates actual flight conditions.

The Stage 4 Demonstration will be the most ambitious flight demonstration; it could include an automatic capture. The key system elements which would be demonstrated include a laser radar for relative state measurements compatible with the required capture accuracies; near vicinity collision avoidance monitoring and prediction; active docking mechanisms or sensors; enhanced SRMS tracking and capture capabilities; and on-orbit maneuver replanner/scheduler.

Successful completion of these objectives will demonstrate an integrated and enhanced operational capability that provides significant benefits for existing and future space flight programs.

## DISCUSSION OF FINDINGS

OMIT TO END

A careful review of the discussions included in Categories 1 through 5 will show many areas of broad consensus and, likewise, many areas of clearly divergent opinion. These often develop from the subjective and honest differences of opinion that result from the absence of data, incomplete understandings, disagreement on the maturity level of various technology and / or different perceptions as to how well various technologies actually might be integrated into a functional subsystem or system.

There was recognition that some of the findings were in the realm of purely technical considerations, issues that could be resolved by further tests, simulations, and component demonstrations. There were also subjective concerns that are not as easily reconciled, such as rate-of-change in the maturation of a technology under various funding scenarios, availability of a near term demonstration at the subsystem level, and whether or not a software capability would evolve with sufficient capabilities to exploit a particular technology. And finally, there were concerns that were addressed to senior program managers and administrators who will be required to define and conduct a cost-constrained, tightly scheduled CTV/AR&C definition program that captures the viable technologies and provides the capability for the SSF resupply missions.

There was agreement that the technology base for AR&C system design is quite large and many options exist for providing the United States with an AR&C system/capabilities for CTV that is clearly advanced over any current capabilities.

There was agreement that the full breadth of technologies available within the U.S. industry and government infrastructures had not been explored at this review because of military classification. Guidance and control capabilities demonstrated within weapons systems utilized in Desert Storm